Simulating 3D Atmospheric Motion Vectors (AMVs) using Water Vapor Feature Tracking

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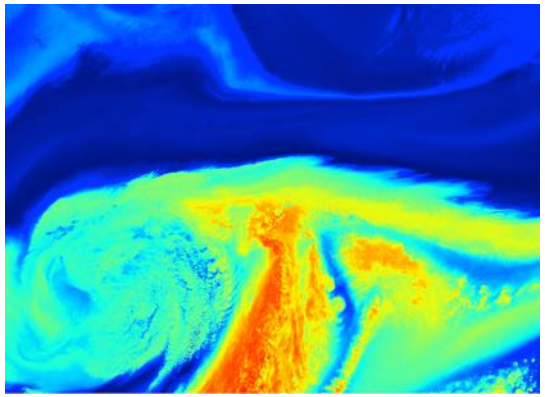
Atmospheric Winds: Systems Approach

- Emerging consensus that a systems approach is needed for space based observation of atmospheric winds
  - Lidar: high accuracy, limited sampling in space and time
  - AMVs (or other approaches): lower accuracy, broader coverage, possibility of relatively rapid revisit
- Key questions:
  - What are the relative strengths / drawbacks of AMVs as a component of a global 3D winds observing system?
  - What is the most effective synergy among various measurement techniques and sampling strategies?

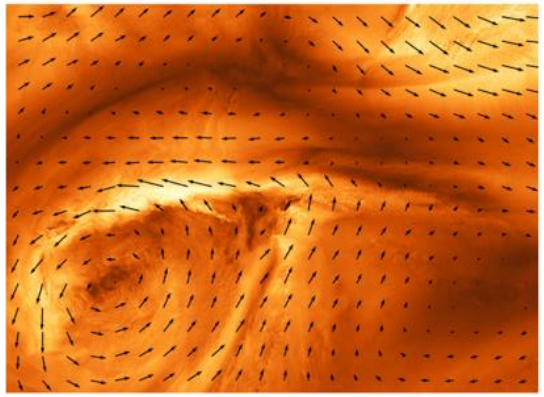
Atmospheric Motion Vectors

- Use of image processing (and other) techniques to track atmospheric motion from sequences of images
- Heritage in tracking clouds and water vapor
- Known to be uncertain, and to contain ambiguities (more on this in a minute)
- Motivation to systematically explore the potential efficacy of AMVs, and quantify their uncertainties
  - More effective use in DA/OSSEs
  - Evaluation of various AMV measurement concepts
  - Potential synergy with other wind measurements

Model Water Vapor



Model Wind Speed and Direction



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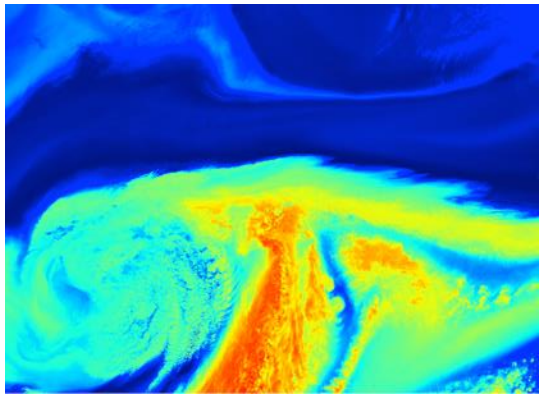
AMV Retrieval Uncertainty Analysis
("Pre-OSSE" - Atlas and Emmitt)

- Produce a high resolution simulation of a representative case (nature run): known water vapor and wind – "truth"
- Retrieve atmospheric motion vectors from this nature run
  - Vary assumptions used in the tracking methodology
  - Modify the instrument sampling properties (spatial and temporal)
- Compare retrieved with true winds
  - Quantify uncertainties by comparing AMVs to the "true" winds
  - Compute RMSE and the state dependence of errors – where/when are AMVs expected to perform reasonably well / poorly?
  - Explore the effect of coarse spatial (horizontal and/or vertical) resolution
  - (Ultimately) use functional uncertainties in forecast OSSEs through collaboration with GMAO and NOAA QOSAP

Model Water Vapor



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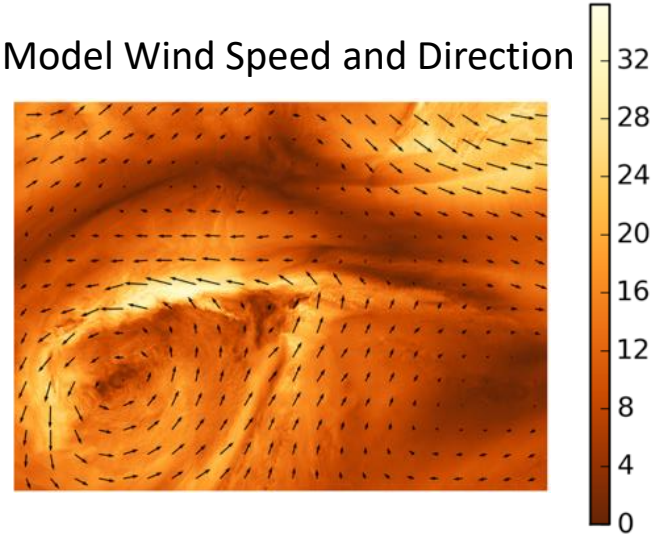
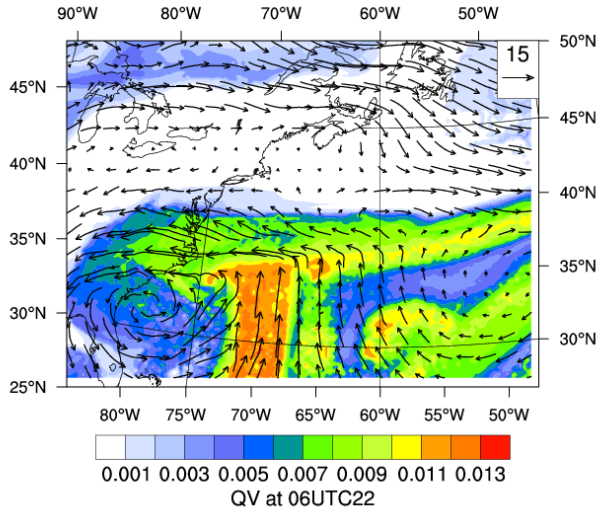
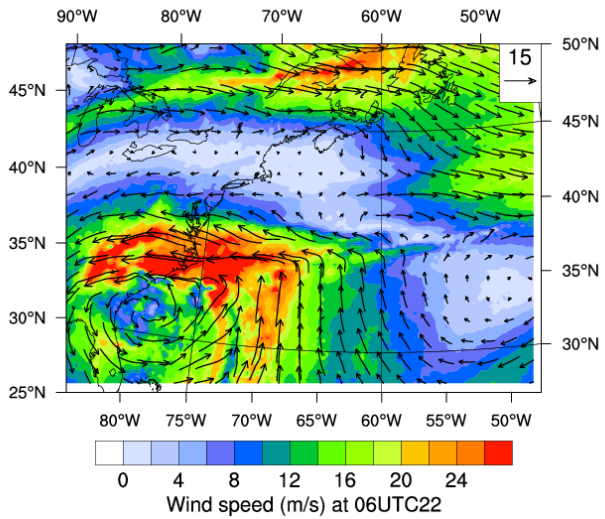


Initial Results: 5-Minute dt, 1.33 km dx,dy

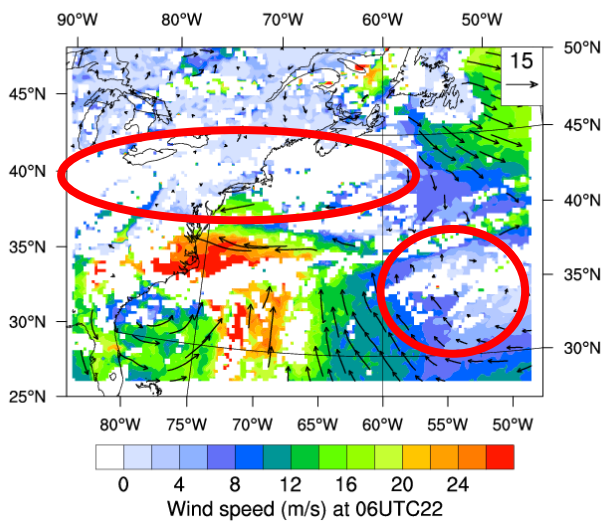
Water Vapor (kg/kg)



"True" Winds (m/s)



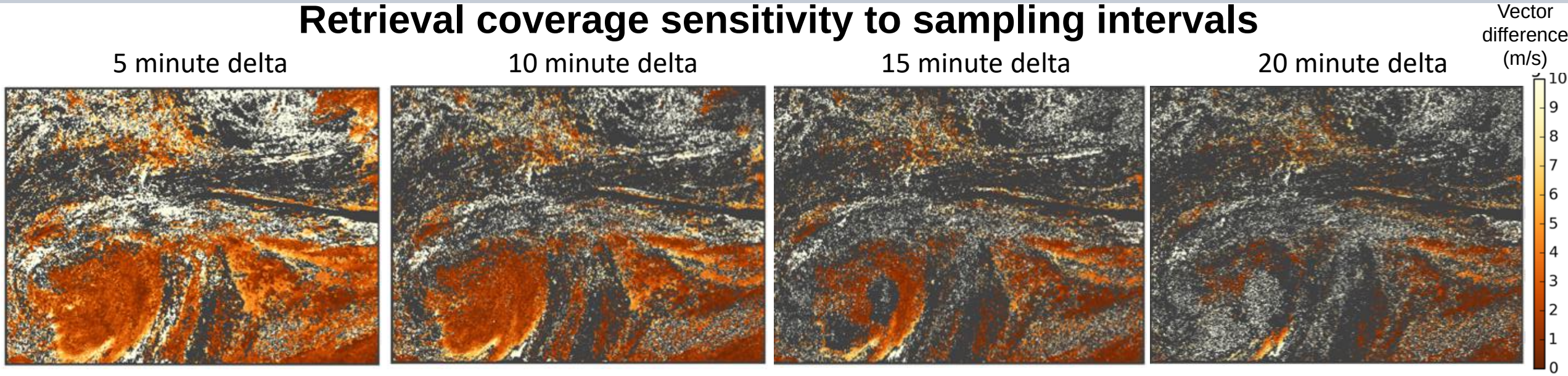
AMVs (m/s)



- Tracking algorithm recovers the approximate distribution of winds in the cyclone
- There are obvious gaps (low water vapor content)
- Explore sensitivity to tracking algorithm settings, time interval, and field of view

Sensitivity to Sampling Interval

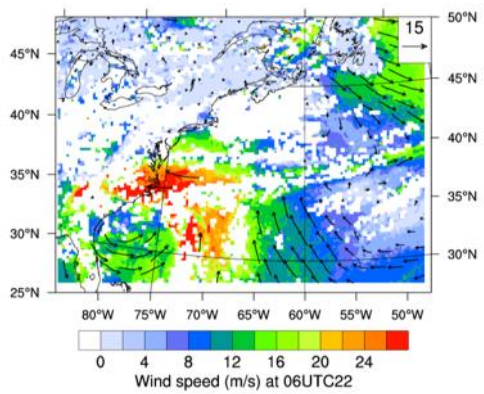
Retrieval coverage sensitivity to sampling intervals



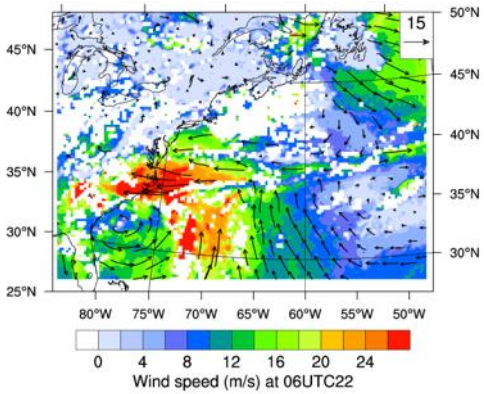
- No cloud mask, vapor and winds are noise-free and at model resolution
- Brighter colors = larger retrieval errors
- Gray areas indicate regions without retrieved wind (algorithm failure)
- **Trade between coverage (rapid revisit) and accuracy (longer revisit intervals)**

Sensitivity to Field of View

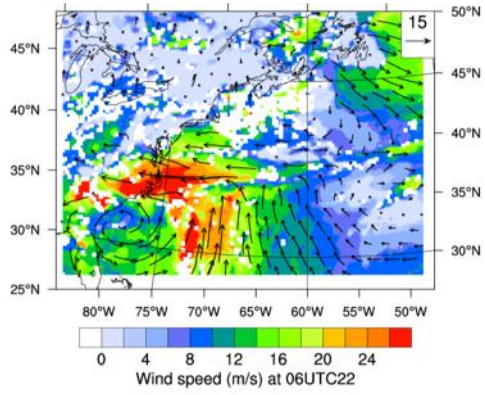
15 km x 15 km FOV



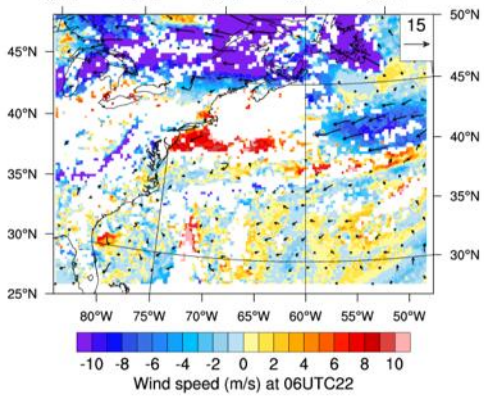
30 km x 30 km FOV



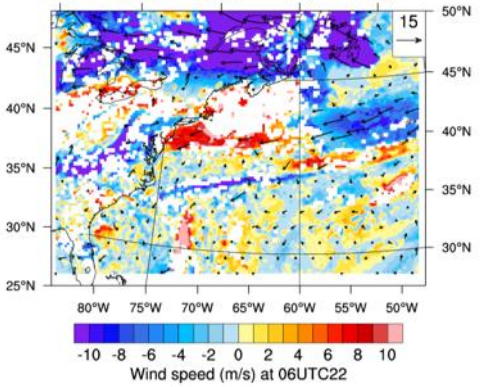
60 km x 60 km FOV



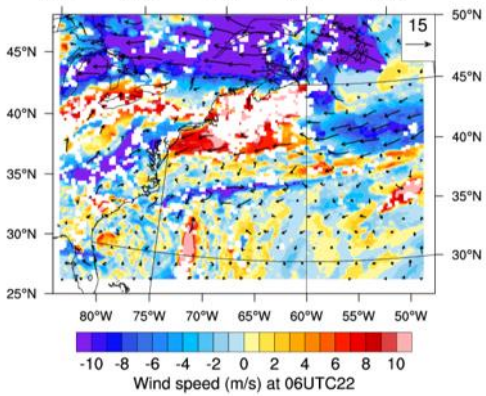
15 km x 15 km FOV



30 km x 30 km FOV



60 km x 60 km FOV

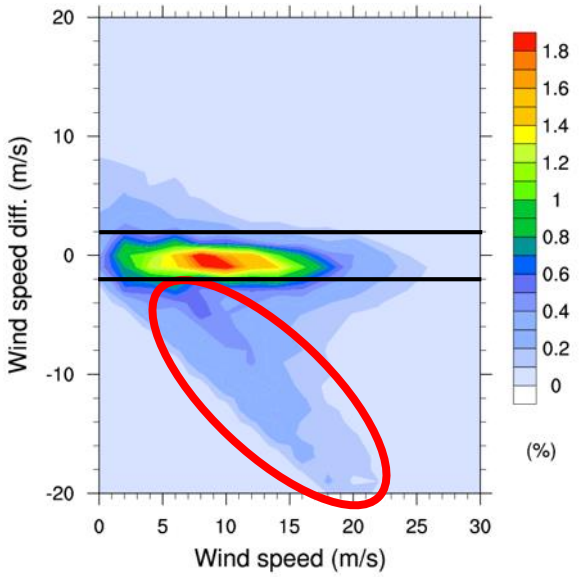


- Tracking over smaller FOV:
  - Higher accuracy
  - Smaller coverage

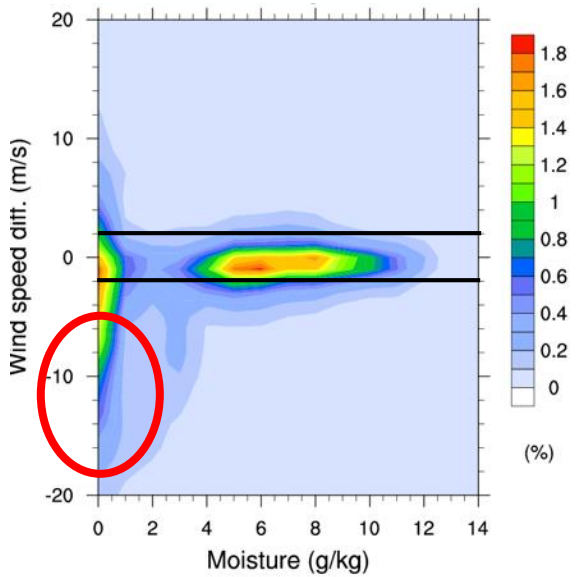
State Dependent AMV Errors

- Retrieval errors are generally within ±2 m/s.
- Large errors occur when moisture content is low or wind direction is perpendicular to moisture gradient.

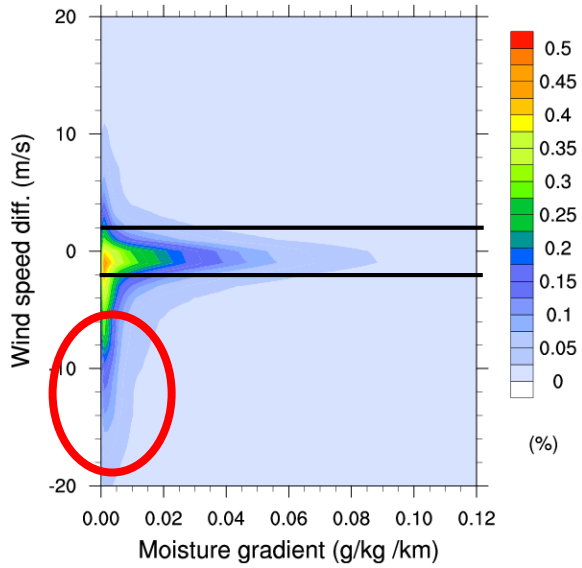
Wind Speed



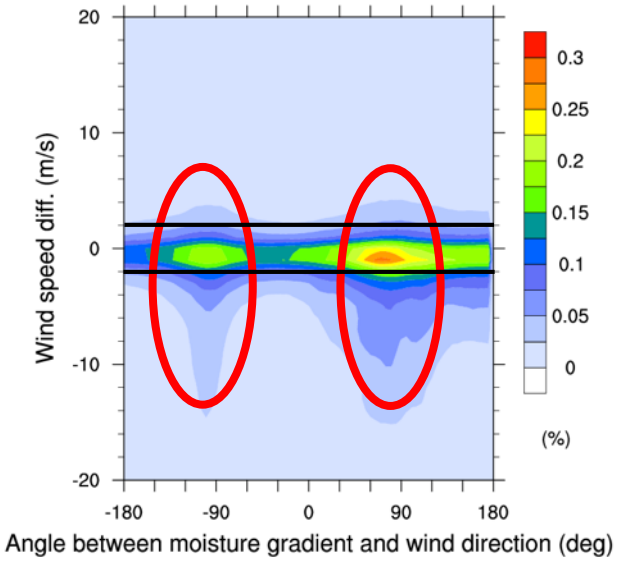
Vapor Content



Vapor Gradient



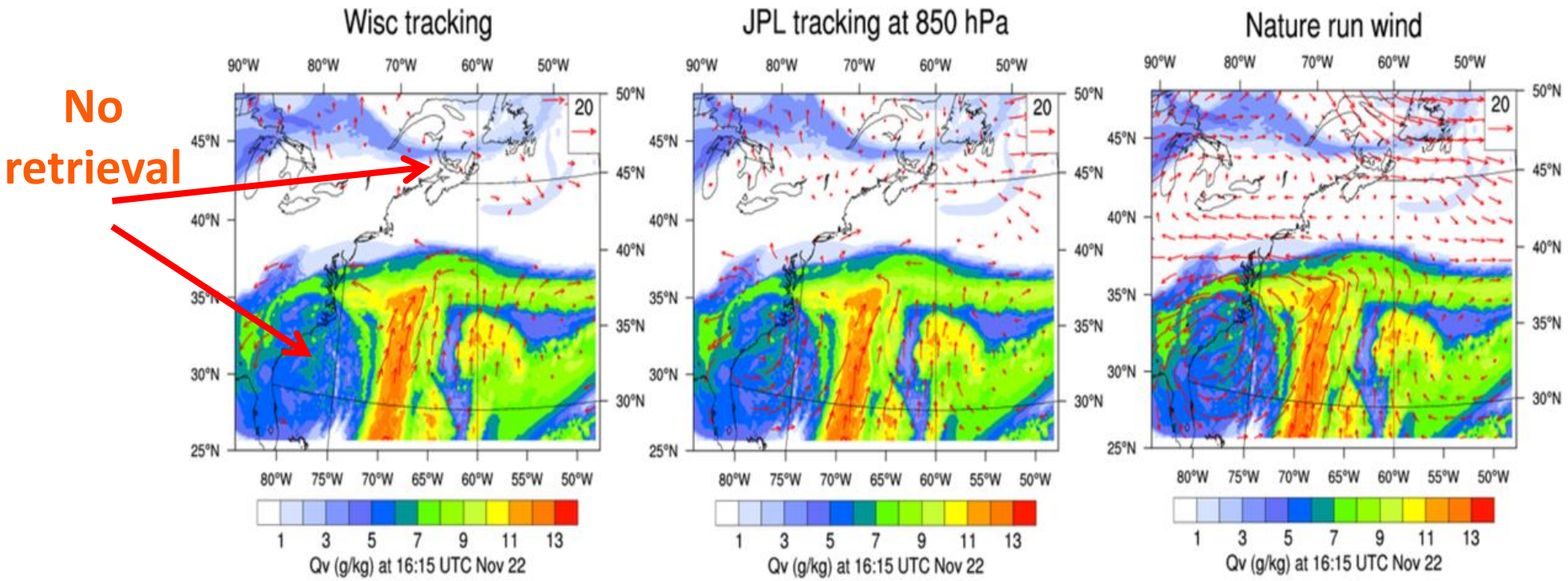
Angle Between
Wind Direction & Vapor Gradient



Y-axis: Difference between retrieved AMV wind speed and nature run.

Comparing Feature-Tracking Algorithms

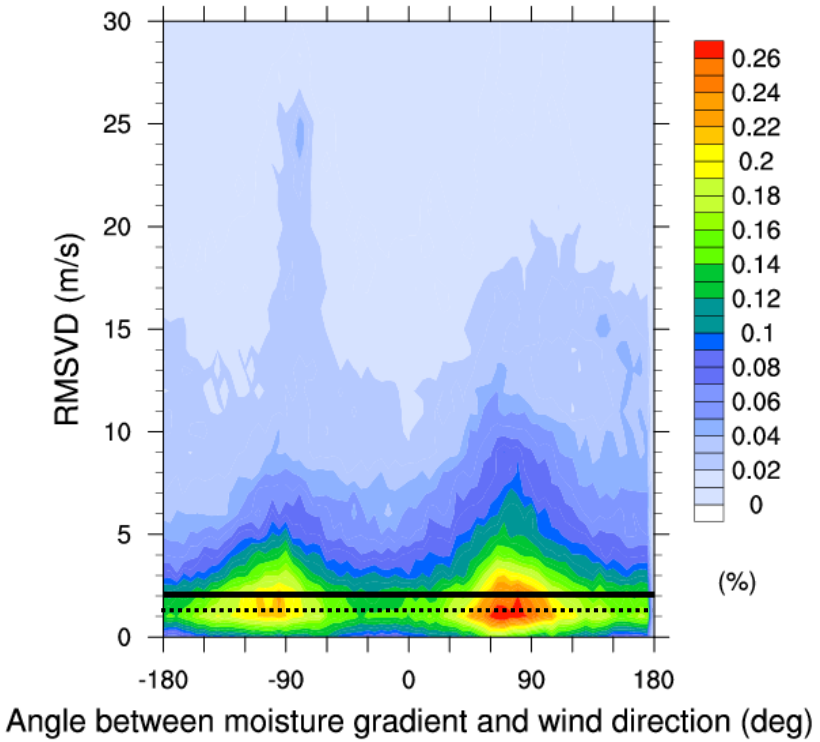
- Operational GOES-R AMV algorithm has more stringent quality control, resulting in smaller RMS error but less coverage of AMV winds.



- U. Wisconsin algorithm: operational GOES-R AMV feature-tracking algorithm
- JPL algorithm: simplified MISR CMV feature-tracking algorithm

Wind Retrieval Uncertainty: Outcomes

- Quantified accuracy of AMVs: most vectors have uncertainties < 2 m/s, however…
- State dependence: error is large where
  - Water vapor content is small
  - Wind vectors are oriented along vapor contours
- Algorithm sensitivity: trade-off between accuracy and coverage
  - Rapid sampling: large coverage, low accuracy
  - Large FOV: smaller coverage, higher accuracy

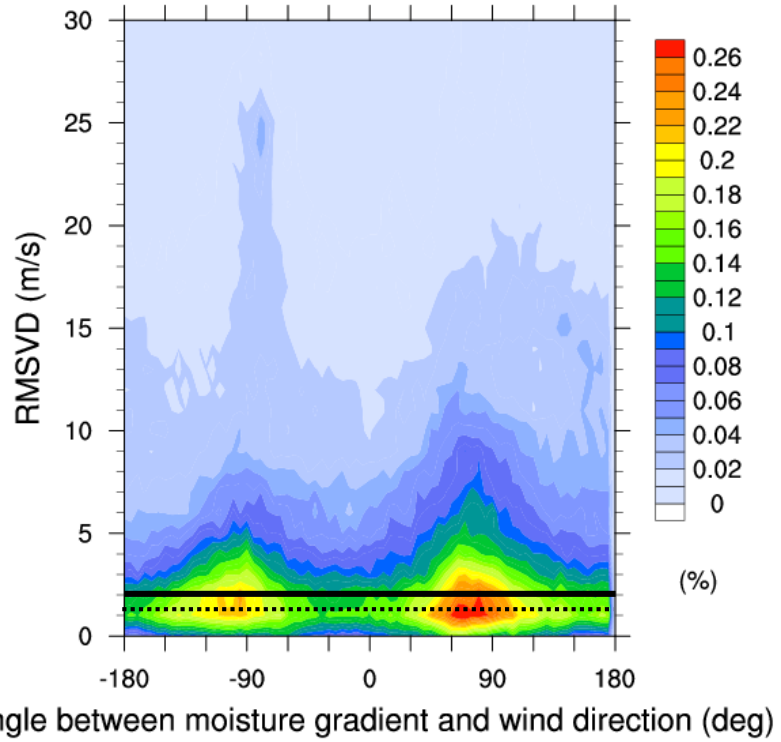


AMV Retrieval Uncertainty: Next Steps

- Caveats:
  - Did not account for clouds/precipitation
  - Tracked full resolution water vapor fields
  - Used a relatively simple feature tracking algorithm
  - Did not apply any image enhancement

Optimal Observing System

Sub-Optimal Algorithm



- Next steps:
  - Mask clouds and/or precipitation – assess yield and uncertainty
  - Smooth fields consistent with IR and MW sounders
  - Employ more sophisticated image tracking techniques (e.g., optical flow)
  - Extend analysis to other regions and times
  - Use state-dependent error characteristics in forecast OSSEs
  - Utilize machine learning to estimate uncertainties from static fields – expand utility of error analysis to a much larger suite of nature runs